Occurrence, Detection, and Habitat Use of Larval Lamprey in the White Salmon River Basin: Pre-Condit Dam Removal

2011 Annual Report

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Introduction

Pacific lamprey *Entosphenus tridentatus* in the Columbia River Basin and other areas have experienced a great decline in abundance (Luzier et al. 2011). They are culturally important to Native American tribes, are ecologically important within the food web, and whose decline provides insight into the impact of human actions on ecological function (Close et al. 2002). Information is lacking on basic biology, ecology, and population dynamics required for effective conservation and management.

Pacific lampreys have a complex life history that includes a multiple year larval (ammocoete), migratory juvenile, and adult marine phase (Scott and Crossman 1973). Larvae and juveniles are strongly associated with stream and river sediments. Larvae live burrowed in stream and river sediments for multiple years after hatching, where they filter feed detritus and organic material (Sutton and Bowen 1994). Larvae metamorphose into juveniles from July to December (McGree et al. 2008) and major migrations are made downstream to the Pacific Ocean in the spring and fall (Beamish and Levings 1991). The sympatric western brook lamprey *Lampetra richardsoni* does not have a major migratory or marine life stage although adults may locally migrate upstream before spawning (Renaud 1997). For both species, the majority of the information on habitat preference of larvae comes from Columbia River Basin tributary systems (Moser and Close 2003; Torgersen and Close 2004; Stone and Barndt 2005; Stone 2006) and coastal systems (Farlinger and Beamish 1984; Russell et al. 1987; Gunckel et al. 2009).

Lamprey ammocoetes are known to occur in sediments of shallow streams but their use of larger river (i.e., >5th order [1:100,000 scale]; Torgersen and Close 2004) habitats in relatively deeper areas is less known. Downstream movement of larvae, whether passive or active, occurs year-round (Nursall and Buchwald 1972; Gadomski and Barfoot 1998; White and Harvey 2003). Anecdotal observations exist regarding larval lamprey occurrence in large river habitats mainly at hydropower facilities or in downstream bypass reaches (Hammond 1979; Moursund et al. 2003; Dauble et al. 2006; CRITFC 2008), impinged on downstream screens, or through observation during dewatering events. Occurrences at hydropower facilities are generally thought to be associated with downstream migration and specific collections of presumably migrating ammocoetes have been made in large river habitats (Beamish and Youson 1987; Beamish and Levings 1991). Sea lamprey *Petromyzon marinus* ammocoetes have been documented in deepwater habitats in tributaries of the Great Lakes, in proximity to river mouths

(Hansen and Hayne 1962; Wagner and Stauffer 1962; Lee and Weise 1989; Bergstedt and Genovese 1994; Fodale et al. 2003*b*), and in the St. Marys River, a large river that connects Lake Superior to Lake Huron (Young et al. 1996). References to other species occurring in deepwater or lacustrine habitats are scarce (American brook lamprey *Lampetra appendix*; Hansen and Hayne 1962). A previous studies of Pacific lamprey and *Lampetra* spp. use of mainstem habitats of the Willamette and Columbia rivers (Silver et al. 2008; Jolley et al. *In press*) indicated Pacific lamprey and western brook lamprey of a broad range in size found utilizing broad areas of the Willamette River and the Columbia River mainstem (Jolley et al. 2011a, 2011b, 2012).

The White Salmon River in southwest Washington originates on Mount Adams and the basin is within lands ceded to the United States by the Yakama Nation. Historically, the basin supported steelhead *Oncorhynchus mykiss*, coho salmon *O. kisutch*, Chinook salmon *O.tshawytscha*, coastal cutthroat trout *O. clarki*, Pacific lamprey and western brook lamprey. However, the construction of Condit Dam in the early 1900's, caused declines in anadromous fish production (Rawding 2000). All fish passage was blocked after fish ladders were destroyed in the early 1900s. Relatively little fish production occurs downstream of Condit Dam due to habitat loss and alteration of the natural flow regime (Rawding 2000).

The Condit Hydroelectric Project, owned by PacifiCorp, includes 144-m long Condit Dam which is 38-m high, with a 38-m spillway. The dam is located 5.3 km upstream from the confluence of the White Salmon River and the Columbia River and is the only dam on the 72-km mainstem White Salmon River. Condit Dam was breached in October 2011 and will be completely removed in the next year. Sediment from the impounded Northwestern Reservoir was allowed to rapidly flush downstream and will continue to flush during the high winter and spring flows. The removal of Condit Dam will reconnect historic fish spawning habitat to the mainstem of the Columbia River. The U.S. Fish and Wildlife Service has partnered with the Yakama Nation, the U.S. Geological Survey, the Washington Department of Wildlife, NOAA Fisheries and PacifiCorp to assess the impact that the removal of Condit Dam may have on fish populations and aquatic habitats in the White Salmon River basin. Pacific lamprey was named as a high priority species for restoration.

Preliminary survey data of lamprey species in the White Salmon River basin indicated that resident western brook lampreys were rare above Condit Dam, while anadromous Pacific lampreys were locally extirpated (Rawding 2000). Habitat surveys have suggested that there is suitable habitat both downstream and upstream of the dam for spawning and rearing of anadromous fish, including lampreys. We began assessing lamprey occupancy and habitat in the White Salmon River basin in 2007. Lampreys have been previously detected in the basin; western brook lampreys were present above Condit Dam, in Northwestern Reservoir, Trout Lake Creek (Silver et al. 2010) and Buck Creek (B. Allen, USGS, personal communication). Lamprey, including Pacific lamprey, have also been detected in the lower White Salmon River (Allen and Connolly 2011; Silver et al. 2010).

This work continued in 2011, focused on the Lower White Salmon River, the reach downstream of Condit Dam to the Columbia River. This reach will be most immediately and dramatically affected by the removal of Condit Dam and release of Northwestern Reservoir sediments. In general, we documented presence or absence of larval Pacific lamprey and *Lampetra* spp. throughout the Lower White Salmon River. Collectively, this work will serve as a baseline for comparison for post-Condit Dam removal studies. In 2011, our specific objectives were to:

1) Document whether larval lamprey occupied the Lower White Salmon River before the breach and removal of Condit Dam

2) Document whether larval lamprey occupied the lower section of two reference rivers, the Wind River and the Klickitat River.

3) Given they were occupied, determine the probability of detecting larval lamprey in these rivers using a deepwater electrofisher.

4) Opportunistically document any lamprey occurrences as the dam removal process commences.

5) Describe the species composition of larval lamprey.

The long-term objectives of the project are to: 1) determine if anadromous lampreys return to previously unavailable spawning habitat after removal of Condit Dam; 2) determine the rate that anadromous lampreys may return after dam removal and 3) determine the effects of dam removal on lamprey spawning and rearing habitats above and below the site of Condit Dam.

Methods

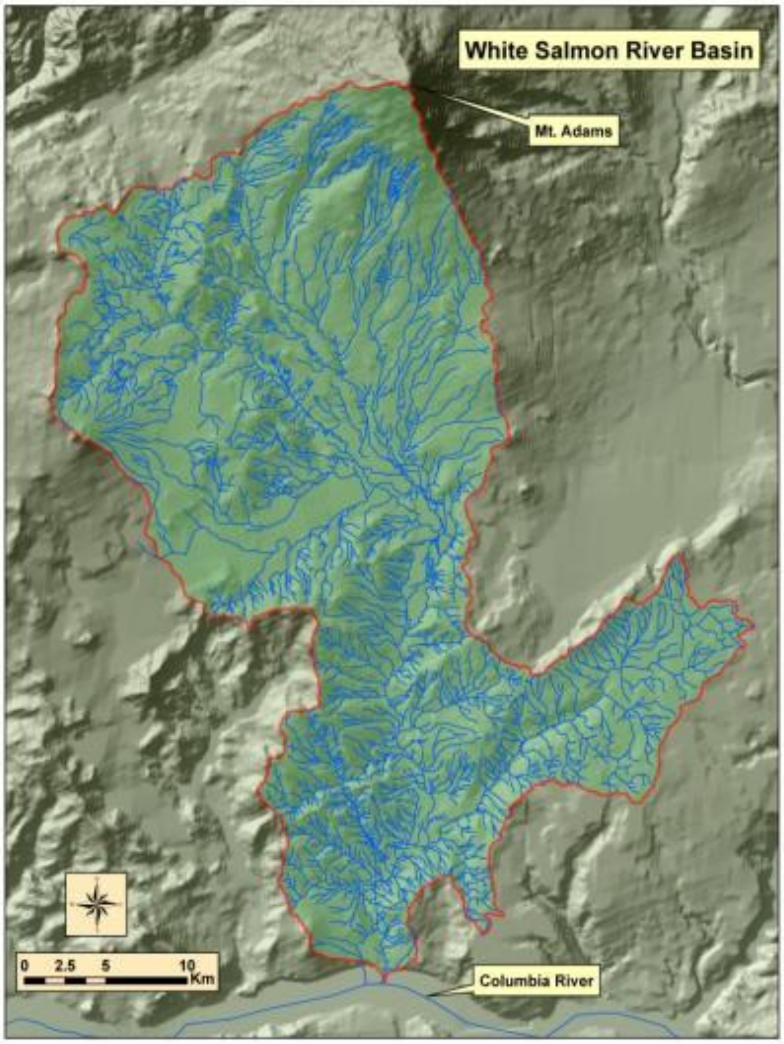

Figure 1. White Salmon River Basin.

We estimated occupancy of larval lamprey in the Lower White Salmon, Wind, and Klickitat rivers by adapting an approach used by Peterson and Dunham (2003) and refined by the U.S. Fish and Wildlife Service (USFWS 2008) to evaluate patch occupancy and detection probability for bull trout *Salvelinus confluentus*. The approach was further applied to studies of larval lamprey in the Willamette and Columbia rivers (Jolley et al. *In press*, 2011a, 2011b). The approach has several requirements: 1) a site- and gear-specific detection probability (assumed or estimated); 2) the probability of presence at a predetermined acceptably low level (given no detection); and 3) random identification of spatially-balanced sample sites that allow estimation of presence and refinement of detection probabilities.

A reach-specific probability of detection, d_{reach}, was calculated as the proportion of quadrats (i.e., 30 m x 30 m sampling quadrat) occupied (i.e., larvae captured) by larval lamprey in the Lower Willamette River, an area known to be occupied. The posterior probability of reach occupancy, given a larval lamprey was not detected, was estimated as

$$(1)\ \mathrm{P}(F|C_o) = \frac{\mathrm{P}(C_o|F)\cdot\mathrm{P}(F)}{\mathrm{P}(C_o|F)\cdot\mathrm{P}(F) + \mathrm{P}(C_o|{\sim}F)\cdot\mathrm{P}({\sim}F)},$$

where P(F) is the prior probability of larval lamprey presence. Although we knew the reach was occupied with larval lamprey, P(F) of 0.5 (uninformed) was used for future study design (i.e., P[F|C_o]) in areas where larval lamprey presence is unknown. P(~F), or 1 – P(F), is the prior probability of species absence, and P(C_o|F), or 1 – d, is the probability of not detecting a species when it occurs (C_0 = no detection; Peterson and Dunham 2003). Patterns of occupancy by river were compared using the Chi-square test for differences in probabilities (Conover 1999).

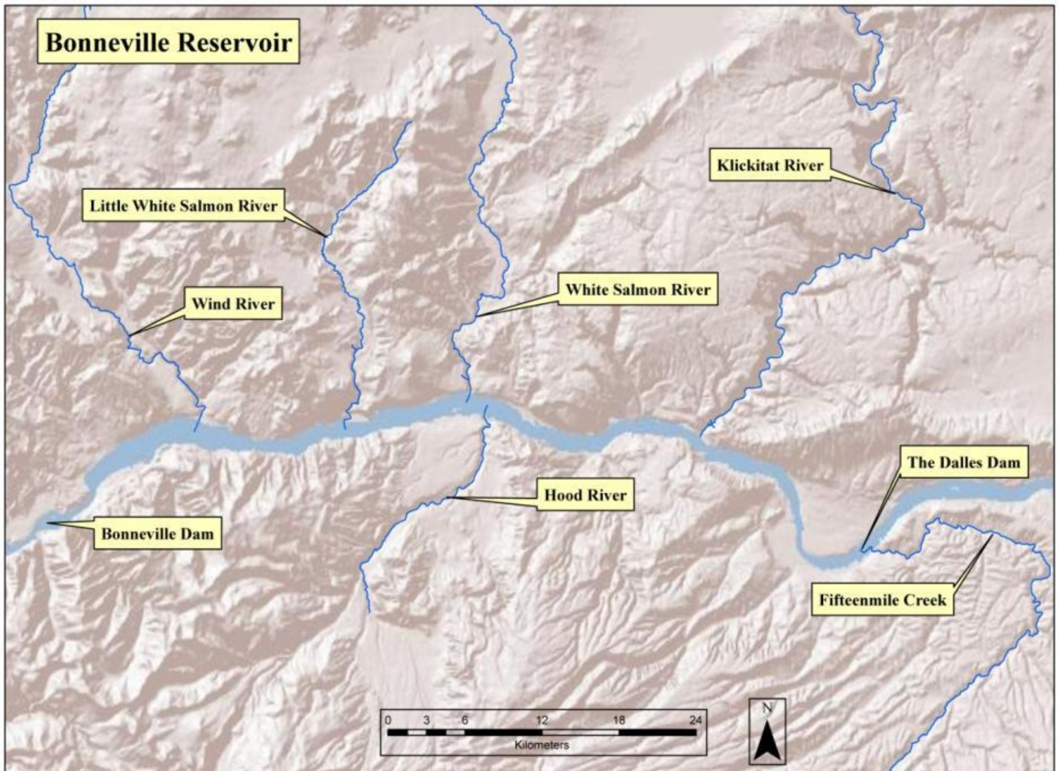

Figure 2. Bonneville Reservoir of the Columbia River and tributary inputs in 2011.

The White Salmon River is a 5th order (1:100,000 scale) river, flows from the south side of 3,742 m peak of Mount Adams and enters the Columbia River at Rkm 269 (Figure 1). The basin covers 1,000 km^2 and Condit Dam is 5.3 km upstream from the confluence of the White Salmon River and Columbia River. The Wind River is a 5th order river; the basin is west of the White Salmon River basin and originates in McClellan Meadows of the western Cascade Mountains. The basin covers 582 km^2 and enters the Columbia River at Rkm 249 (Figure 2). Shipherd Falls is located 3 km from the mouth that historically blocked anadromous fish passage but a ladder was constructed in the 1950's providing fish passage (Connolly et al. 1999). The Klickitat River is a 5th order river; the basin in east of the White Salmon River basin and originates near Cispus Pass in the Goat Rocks region of the Cascade Mountains. The basin covers 3,496 km^2 and enters the Columbia River at Rkm 290 (Figure 2). It is one of longest undammed rivers in the Pacific Northwest although the gradient is steep and there are many waterfalls which may be challenges to fish passage (Sharp et al. 2000). These two rivers were chosen as reference sites to the White Salmon River and are of comparable size, function, and proximity. All rivers presumably have fine sediments originating from the Cascade Mountains that would provide adequate rearing habitats for larval lamprey.

The lower reaches of these rivers were sampled in May-June 2011 for larval lamprey occupancy. We sampled from the mouth of the Lower White Salmon River upstream 1.4 km to the first riffle where boat navigation was no longer possible. We used this distance (1.4 km) to guide a similar sampling effort in the Klickitat River and Wind River. We ultimately sampled upstream 1.0 km in the Klickitat River and approximately 1.25 km in the Wind River to where we could no longer navigate a boat due to shallow water (Figure 3). A sampling event consisted of using a deepwater electrofisher (Bergstedt and Genovese 1994) in a 30 m x 30 m quadrat. This quadrat size was selected based on the previous experience of sea lamprey researchers in the Great Lakes (M. Fodale, USFWS, personal communication) as their sampling approach evolved from a systematic to adaptive approach (Fodale et al. 2003*a*). A description of

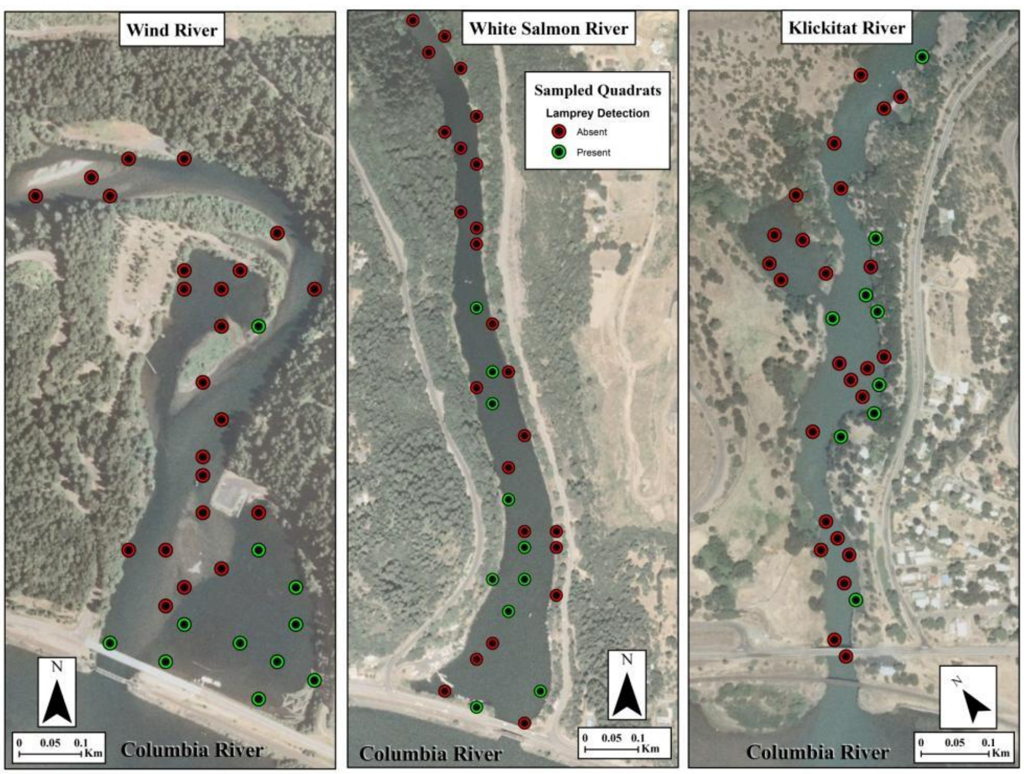

Figure 3. Lower reaches of the Wind River, White Salmon River, and Klickitat River sampled for lamprey occupancy in 2011.

the complete configuration of the deepwater electrofisher is given by Bergstedt and Genovese (1994) and sampling was standardized. The bell of the deepwater electrofisher was lowered from a boat to the river bottom. The electrofisher delivered three pulses DC per second at 10% duty cycle, with a 2:2 pulse train (i.e., two pulses on, two pulses off). Output voltage was adjusted at each quadrat to maintain a peak voltage gradient between 0.6 and 0.8 V/cm across the electrodes. Suction was produced by directing the flow from a pump through a hydraulic eductor prohibiting ammocoetes from passing through the pump. Suction began approximately 5 seconds prior to shocking to purge air from the suction hose. Shocking was conducted for 60 seconds, and the suction pump remained on for an additional 60 seconds after shocking to ensure collected ammocoetes passed through the hose and emptied into a collection basket (27 x 62 x 25 cm; 2 mm wire mesh). The sampling techniques are described in detail by Bergstedt and Genovese (1994) and were similar to those used in the Great Lakes region (Fodale et al. 2003*b*) and the Willamette River (Jolley et al. *in press*).

We used a Generalized Random Tessellation Stratified (GRTS) approach to select sampling quadrats in a random, spatially-balanced order (Stevens and Olsen 2004). We developed a layer of 30 m x 30 m quadrats using ArcMap 9.3 (Environmental Systems Research Institute, Redlands, California) which was overlaid on each lower river section (Figure 4). There were 143, 205, and 253 quadrats in the lower reaches of each the Klickitat River, White Salmon River, and Wind River, respectively (Table 1). The Universal Trans Mercator (UTM) coordinates representing the center point of each quadrat were determined. The GRTS approach was applied to all quadrats to generate a random, spatially balanced sample design for these areas. This approach was used to generate an unbiased sample design that would allow the quantification of detection probabilities.

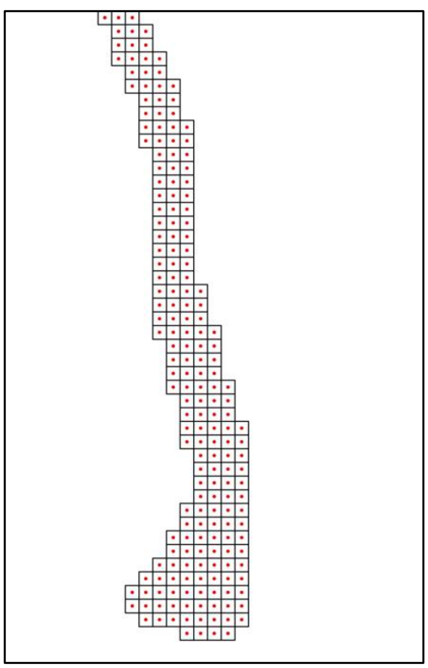

Figure 4. A schematic showing a hypothetical section of a river divided into 30 m x 30 m quadrats and associated UTM center points.

The quadrats were ordered sequentially as they were selected in the GRTS approach and the lower numbered quadrats were given highest priority for sampling. Based on previous occupancy sampling in a variety of areas, with detection rates ranging from 0.02 to 0.32, we used a relatively low to moderate detection rate of 0.07 (given an area was occupied). A minimal sampling effort of 17 quadrats is therefore necessary to achieve 80% certainty of lamprey absence when they are not detected (see Jolley et al. *in press*). To be conservative, we doubled that sampling rate to 34 quadrats. The GRTS approach allows increasing the sample effort, while maintaining a random and spatially-balanced design, when warranted (i.e., low detection). Quadrats that were not feasible due to dewatered conditions or excessive velocity (Table 1) were eliminated from the sample and all subsequent quadrats were increased in priority.

Collected lampreys were anesthetized in a solution of tricaine methanesulfonate (MS-222), identified as Pacific lamprey or *Lampetra* spp. according to caudal pigmentation (Goodman et al. 2009), and classified according to developmental stage (i.e., ammocoete, macrophthalmia, or adult). Lampreys were measured (TL in mm), placed in a recovery bucket of fresh river water, and released after resuming active swimming behavior. Length-frequency histograms were constructed for each species to describe size structure.

Concurrent to each sampling event a sediment sample was taken from the river bottom by using a Ponar bottom sampler (16.5 cm x 16.5 cm). A 500 mL sample was labeled, placed on ice, and returned to the lab. Samples were oven-dried for 12 hours at 100°C to remove all water. Sediment size was characterized by weighing the component portions of the sample that collected on a set of sieves (opening sizes: 37.5 mm, 19 mm, 9.5 mm, 1 mm, 0.5 mm, and remainder less than 0.5 mm). Percent organic content of replicate samples was determined using loss-on-ignition methods (Heiri et al. 2001) by combusting organic material at 500-550 C for six hours.

Results

We visited 36 to 41 quadrats in each river and ultimately sampled 34 in each river. The feasibility of being able to sample a given quadrat ranged from 83% to 94% (Table 1). Some were not sampled because they were not feasible (dewatered conditions or excessive velocity). Larval lampreys occupied all rivers. Pacific lamprey and unidentified lamprey larvae occupied the lower Klickitat River (d=0.27, Table 1). Pacific lamprey, western brook lamprey, and unidentified lamprey occupied the lower White Salmon River (d = 0.29) and lower Wind River (*d* = 0.33, Table 1). There was no difference in the detection probabilities among river reaches (chi-square=0.28, df=2, *P*>0.05).

Table 1. Total number of quadrats delineated, visited, sampled, and occupied and species present at three rivers in 2011.

	Quadrats								
Reach	Total	Visited	Sampled	Occupied	*d*	Pacific lamprey	Western brook lamprey	Unid	Total
Lower Klickitat River	143	41	34	9	0.265	13	0	2	15
Lower White Salmon River	205	36	34	10	0.294	5	11	3	19
Lower Wind River	253	39	34	11	0.324	13	9	4	26

Lamprey larvae ranged in size from <20 mm (typically those escaped through the mesh in the collection basket) to 160 mm (Figure 5). Differences in total length were detected. The river*species interaction was significant (ANOVA, *F*=4.95, df=1, *P*=0.03). Specifically, mean TL of western brook lamprey (116 mm) was greater than Pacific lamprey (71 mm) in the lower Wind River (*F*=10.36, df=1, Bonferroni correction, *P*=0.0043). No other differences were detected although sample sizes were marginal. Finally, one gravid adult western brook lamprey was collected in the lower White Salmon River (TL = 112 mm). Depths sampled ranged from 0.6 to 9.1 m and larvae were detected in depths ranging from 1.5 to 7.1 m.

Mean percent organic content ranged from 2.4 to 10.5% and was significantly lower in the Lower Klickitat River than the Lower White Salmon or Lower Wind River (ANOVA, *F*=10.70, df=2, *P*<0.0001; Table 2). Fine sediments were present in all river reaches although the Lower Wind River had a higher percentage of moderate-sized substrate (ANOVA, *P*<0.05). Large cobble/boulder substrate (too large for the dredge) was detected at 11 sites (32%) at the White Salmon River and at 7 sites (21%) at the Wind River. Larval lamprey only occupied quadrats dominated by the two smallest substrate size categories (Figure 6).

Condit Dam pre-breach activities

Larval lampreys were also observed in the White Salmon River in supplemental efforts to this sample design. A fish salvage operation was conducted during dewatering activities at the face of Condit Dam associated with dam removal operations. Western brook lamprey larvae were observed in this area (R. Engle, USFWS, personal communication). Northwestern Reservoir was also lowered in preparation for dam removal activities and extensive areas of the lake bed were dewatered. We haphazardly sampled isolated pools in the lake bed with a backpack electrofisher (see Silver et al. 2010 for description). Lamprey were abundant in these disconnected pools. Thirty-two larvae were collected and returned to the lab for species identification and saved as voucher specimens. All were western brook lamprey; there were 30 larvae and 2 adults. There was a broad size range (61-156 mm TL) indicating a potential range in age. Numerous dead and dying larvae were observed on the sediment surface in dewatered areas (Figure 7). Finally, when Condit Dam was breached on 26 October 2011, large amounts of sediment from Northwestern Reservoir were flushed downstream in 45 min. Sediment rapidly accumulated in many downstream areas including the Spring Creek National Fish Hatchery Acclimation holding raceways. Hundreds of larval lamprey were observed in these areas (R. Engle, USFWS, personal communication; Figure 8) and all appeared to be western brook lamprey (M. Mesa, USGS, personal communication). Northwestern Reservoir was the presumable source of these lampreys although this was not explicitly monitored.

Table 2. Sediment mean percent in size categories (mm), and organic content in lower river reaches in 2011. Standard errors are in parentheses.

	Mean percent particle size (mm)							
Reach	>37.5	37.5-19.0	19.0-9.5	9.5-1.0	1.0-0.5	<0.5	Mean percent organic content	Number
Lower Klickitat River	0 (0)	0 (0)	0 (0)	8.2 (2.9)	20.2 (3.7)	71.6 (5.6)	2.4 (0.4)	34
Lower White Salmon River	0 (0)	0 (0)	0 (0)	7.1 (2.5)	6.3 (3.3)	86.5 (5.1)	7.1 (1.7)	21
Lower Wind River	0 (0)	7.1 (3.6)	3.6 (2.0)	13.9 (3.8)	7.4 (2.9)	68.1 (8.1)	10.5 (1.9)	25

Findings

Larval Pacific lampreys occupied all river reaches, and western brook lamprey occupied the White Salmon River and Wind River. Our findings are similar to those of studies conducted in the Great Lakes, where larval sea lamprey and American brook lamprey *Lampetra appendix* have been found in lentic areas (Hansen and Hayne 1962), deepwater tributaries (Bergstedt and Genovese 1994; Fodale et al. 2003*b*) and large rivers (Young et al. 1996). This work also corroborates our earlier findings that Pacific and western brook lampreys inhabit relatively deep, mainstem areas of the Willamette and Columbia rivers (Jolley et al. *in press*, 2011a, 2012). In addition, these larvae likely represented multiple age classes. Small larvae likely recruited to these areas relatively recently. It is unknown if the larval lampreys actively migrated from headwater tributaries, were passively washed out of upstream habitats, hatched in the mouths of these rivers, or some combination of these. Deepwater river spawning of lamprey has not been documented although lentic spawning has been observed (Russell et al. 1987). The reservoirs created by many dams on the Columbia River may create habitats (e.g., relatively slower velocity, increased sediment deposition) that didn't exist prior to dam construction or were likely less abundant. Larval lamprey may use these areas at a disproportionally higher rate than pre-dam construction. The lowermost portions of the tributaries studied are affected by Bonneville Reservoir. Impounded areas of slower velocity, deeper, habitats containing fine sediments exist. It is unknown if there is a "wash in" effect from Bonneville Reservoir, that is the increased abundance of larvae in these habitats may have migrated in from the reservoir. The relatively high detectability of larval lamprey in the lower White Salmon River mouth was notable. Condit Dam on the White Salmon River has blocked all fish passage and sediment movement downstream for many years. The presence of larval Pacific lamprey in the Lower White Salmon River means that either adults spawning in the reach below the dam or that larvae recruited to this area from a different source (e.g., reservoir). Understanding the source of these larvae would be extremely valuable. Identifying discrete populations may allow monitoring larval dynamics, spatially and temporally. Condit Dam was breached in October 2011 and will be completely removed in the next year. Sediment from the impounded Northwestern Reservoir was allowed to rapidly flush downstream (see cover image). Formation of a new river delta will be a dynamic process and will be

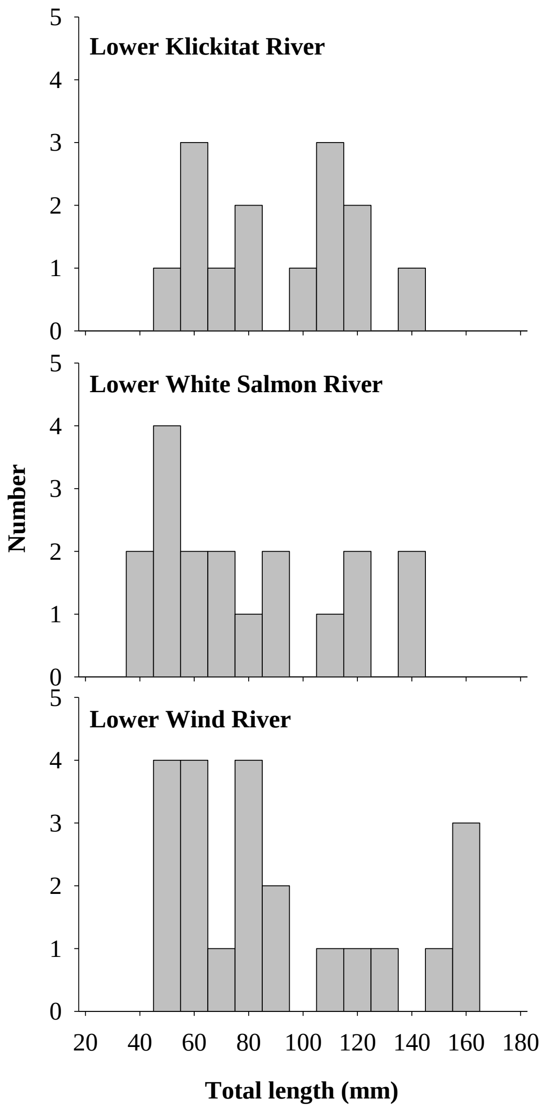

Figure 5. Length-frequency histograms for larval Pacific lamprey and western brook lamprey in three rivers in 2011.

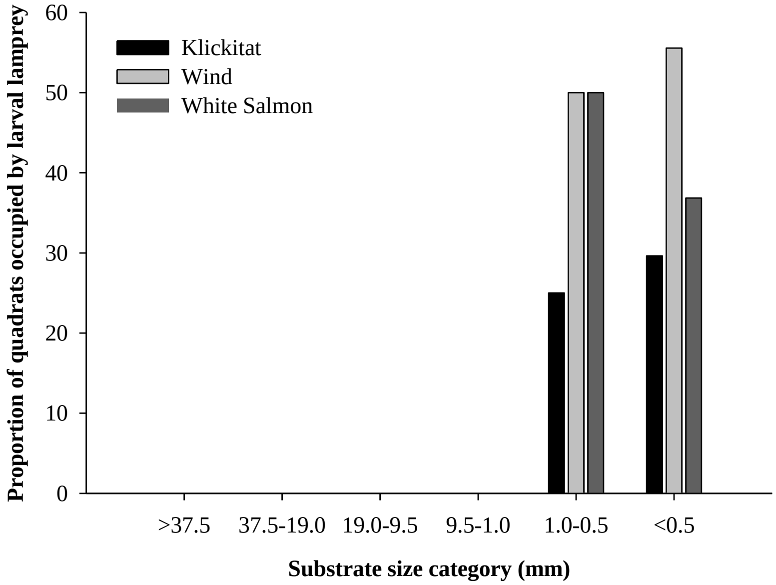

Figure 6. Percent of quadrats occupied by larval lamprey categorized by the dominant substrate size.

monitored as well as the Lower White Salmon River as part of a concurrent and related project. This work will serve as baseline data prior to the dam removal.

Studies of ammocoete migration/dispersal distance, as well as passage routes and survival rates at Columbia River dams would significantly improve our understanding of the relative importance and potential impacts of mainstem residency on larval lamprey. Overall, larval lamprey distribution and habitat usage of mainstem areas in the Columbia River and its tributaries, including above and below hydropower projects, remains largely uninvestigated.

Detection of larval lampreys was the highest observed in all of our mainstem lamprey research to date (Jolley et al. 2012) indicating a presumably increased local population size (relative to other areas; Royle and Nichols 2003), enhanced rearing conditions in these areas and/or tributaries serving as source populations for larvae in the mainstem. Both the Wind River and Klickitat River are known to have populations of larval lamprey although information is scarce (Connolly et al. 1999; P. Luke, Yakama Nation Fisheries, personal communication). We captured multiple larvae at 6%, 12%, and 18% of quadrats sampled in the lower Klickitat, White Salmon, and Wind River, respectively. Relatively high occupancy rates coupled with different levels of occupancy (i.e., n>1 individual detected) introduce the ability to incorporate multi-state occupancy models which are an extension of standard occupancy models (MacKenzie et al. 2006; Nichols et al. 2007). These models can be particularly useful to model habitat effects on occupancy. Future work might couple thorough measures of habitat variables to be used as co-variates to the detection probability models. Overall, lamprey larvae of multiple sizes and species occupied the lower reaches of tributaries to Bonneville Reservoir; we provide empirical

Figure 7. Dead western brook lamprey larvae in an isolated pool of Northwestern Reservoir during dewatering, in 2011.

evidence for this. These areas should not be overlooked as relevant to the conservation and management of these imperiled species. This topic has been largely ignored and further research and monitoring is needed to address larger uncertainties in population trends, recruitment, and mortality.

Acknowledgements

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Figure 8. Western brook lamprey larvae observed on newly transported sediment at the Spring Creek National Fish Hatchery acclimation ponds on the White Salmon River after the breach of Condit Dam in 2011.

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